INTEGRATION OF CT/PET IMAGES FOR THE OPTIMIZATION OF RADIOTHERAPY PLANNING

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Abstract- **A procedure is presented, based on the combined use of two different tomographic imaging modalities (PET and CT), aimed at the optimization of radiotherapy planning. The combined use of functional PET and anatomical CT studies allows a better definition of the tumour mass with respect to the conventional CT based approach. The proposed procedure consists in: a) spatial registration of CT and PET studies; b) contour drawing based on the combined observation of PET and CT. The set of contours thus obtained, defining optimized volumes of interest for radiotherapy, can be exported to the treatment planning system for designing the radiation beams geometry. The accuracy of the image registration was evaluated by phantom studies and found to be less than 2 pixels in plane and less than slice thickness axially, with respect to CT.**
The application of the procedure to the case of a patient affected by pancreatic tumour is presented, showing how the treatment planning can be improved by multimodal CT/PET information.
Keywords **- Radiotherapy, multimodal registration, PET.**

I. INTRODUCTION

Principal aim of radiotherapy is to obtain maximum control on tumour growing and, at the same time, maximum limitation of dose-related damages to the surrounding healthy tissues. As demonstrated in radiobiological and clinical studies, the probability of local tumour control increases by delivering higher radiation dose to neoplastic cells. The problem is then to accurately identify the extension of the tumour mass and of the tissues involved in the neoplastic degeneration (e.g. lymphnodes), in order to optimize the irradiation geometry, concentrating radiation dose to the tumour and minimizing dose release to the surrounding tissues, with special care to radiosensitive critical organs. The modern equipments for irradiation delivery are able to provide shaped and/or intensity modulated radiation beams, which can accurately match the shape of the tumour, conventionally visualized by X-ray Computed Tomography (CT) [1]. To this respect, the integration of CT and PET multimodal tomographic images, which describe anatomical and functional aspects of the tumour, respectively, is proposed to improve radiotherapy planning, by allowing a more accurate definition of the irradiation target [2]. In fact, CT provides the anatomical details, while PET shows the increased metabolic activity of the tumour and of the involved lymphnodes. In several applications, the integration of CT and PET images has been demonstrated to improve the diagnostic accuracy [3][4].

In this work, a procedure to improve treatment planning in radiotherapy is described, based on the integration of multimodal CT/PET studies. The application of the procedure to the case of a patient affected by pancreatic tumour is presented.

II. METHODOLOGY

A. Image acquisition

For CT imaging, a Tomoscan AV spiral CT scanner (Philips Medical System) was used, with 510 mm FOV. From spiral acquisition data, tomographic images were reconstructed, by using a 180° interpolator, on 256x256 matrices (pixel size 1.64 mm).

The PET system used was a GE Advance tomograph (General Electric Medical System) consisting of 18 rings of Bismuth Germanate detectors, yielding 35 transaxial images (4.3 mm thick) and covering 15 cm axial FOV. The system was equipped with two rotating ^{68}Ge line sources, for transmission measurements, used to correct emission data for radiation attenuation. Tomographic images were reconstructed on 128x128 matrices (pixel size 4.29 mm).

B. Integration procedure

The procedure for including multimodal CT/PET information in the treatment planning consists of the following steps:

1) Spatial registration of CT and PET volumes, by using a "surface matching" registration technique [5]. This method provides the set of rigid transformation parameters required to align two different tomographic studies of the same subject in a unique spatial reference system, by minimizing the distance between correspondent surfaces, extracted from the two studies. In this work, tomographic studies of the thoraco-abdominal district were considered and surfaces corresponding to lungs contours were used. As PET emission images are poor of anatomical information, PET lung surfaces were extracted from the PET transmission study.
After registration, the PET emission study is represented in the spatial reference system of the CT volume, which, in the conventional treatment radiation plans, represents the reference modality for the calculation of the spatial dose distribution.

2) Drawing of contours relative to the tumour mass and to critical organs, based on the combined observation of corresponding CT and PET images (side-by-side display).
As usually the commercial treatment planning systems are based on the analysis of CT images and do not allow simultaneous analysis of images derived from different modalities, a software package was developed (Matlab 5.3 language) on a dedicated analysis workstation. The package provides a set of tools for the interactive drawing of body contours describing the irradiation target volume and the

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dose-limiting organs, on a multimodal display, and allows such contour sets to be exported to the system devoted to the treatment planning (in this work: Cadplan-Varian).

C. Registration accuracy

A phantom simulating the body shape [6] was used to evaluate the accuracy of the registration technique in correlating CT and PET images relative to the thoraco-abdominal district. Twenty-eight PET point markers were positioned spread on the surface and within the phantom (small catheters 2mm long, 1mm diameters, filled with ^{18}F). An emission PET study was performed at two adjacent bed position to cover an axial FOV of 30 cm, followed by a transmission study. The phantom was then moved to CT and the PET markers were replaced with CT point markers (lead spheres, 1mm diameter). Three subsequent CT studies were acquired (CT1,CT2,CT3, 5 mm slice thickness), varying the phantom position, in order to simulate different misalignements with respect to the PET study. In particular, in CT1 and CT2 studies, the phantom was positioned trying to reproduce the PET position, while in the CT3 study a misalignement was simulated (on the order of 3°-5°). An additional CT acquisition (CT4) using a larger slice thickness (10mm) was performed, in order to reproduce a CT protocol widely used for radiotherapy planning.

The surface matching registration technique was applied to each pair of CT/PET studies. The coordinates of the point markers were then identified on the CT and PET images, in the voxels with the highest signal intensity.

Accuracy of the registration technique was defined as the mean distance between correspondent markers position in the transaxial plane (ΔP), along the axial direction (ΔZ) and in the 3D space (ΔS).

D. Patient study

A patient affected by an unresectable pancreatic tumour was considered. The patient underwent a PET-FDG study of glucose metabolism. One hour after an i.v. administration of FDG (100microCi/Kg body weight), the patient was positioned supine, with arms over the head and a whole-body emission scan (5 minutes per bed position) was started covering a field of view from neck to pelvis. Transmission scans (3 min per bed position) were then performed on thorax and upper abdomen. Raw data were corrected for measured attenuation using segmented transmission data and then reconstructed in transaxial images.

The patient underwent then a CT examination. Particular attention was dedicated to set the patient on the CT bed in the same position as during the PET study. In order to reproduce PET conditions, CT images were acquired with the patient normally breathing. CT scan covered the same axial body length as in PET (7 mm axial slice thickness). After acquisition, CT and PET images were transferred to the analysis workstation and the two studies were coregistered.

The radiotherapy target volume, defined by the tumour mass and pathological lymphnodes, was delineated in two different ways: 1) contour drawing on the CT volume alone; 2) contour drawing by using simultaneous visualization of registered CT and PET volumes.

Based on these two sets of contours, two different irradiation plans were defined. As the combined use of CT and PET allows the best identification of the tumour extension, the two plans were compared with respect to the CT/PET target volume, in terms of dose-volume histograms.

III. Results

A. Registration accuracy

In Table 1 values of registration accuracy are summarized for the phantom experiments. In all the experiments, transaxial mean error (ΔP) is less than pixel size used in PET, which is the modality with worse spatial resolution; along the z direction registration accuracy (ΔZ) is worse, due to the degradation of CT resolution in the axial direction (5mm or 10 mm slice thickness) with respect to the in-plane resolution.

The mean error in the 3D space does not exceed 6.5mm. To note, worse registration accuracy is obtained when the two studies to be registered are more strongly misaligned during acquisition (bad CT/PET repositioning, CT3/PET) and when a larger CT slice thickness is chosen (bad axial sampling, CT4/PET).

TABLE I
VALUES OF ACCURACY RELATIVE TO CT/PET PHANTOM STUDIES

	ΔP (mm)	ΔZ(mm)	ΔS(mm)
CT1/PET	2.10±1.22	2.41±2.81	4.07±2.28
CT2/PET	2.28±1.49	1.29±2.21	3.42±1.78
CT3/PET	2.61±1.49	4.67±3.28	6.39±2.49
CT4/PET	2.54±1.15	3.87±4.89	6.10±3.94

B. Patient study

Fig, 1 shows a registered CT and PET representative slice: the pancreatic tumour is difficult to define at CT and appears as a hypermetabolic area on the PET image, which thus provided an essential information in the identification of the tumour extension. The contour relative to the tumour volume, interactively drawn on CT and PET images, is overlapped on both CT and PET. In fig. 2 the target volumes as identified by CT alone and by combined CT/PET data are shown. In this case, it is possible to note that, when PET data are available, a major extension of the target volume is found in the caudal direction. Fig. 3 shows the dose-volume histograms of the two radiation plans relative to the CT/PET target volume. A considerable difference between the two treatments can be observed. In particular, by using the irradiation plan based on CT data alone, only 82% of the target volume receives an adequate dose coverage (> 50 Gy).

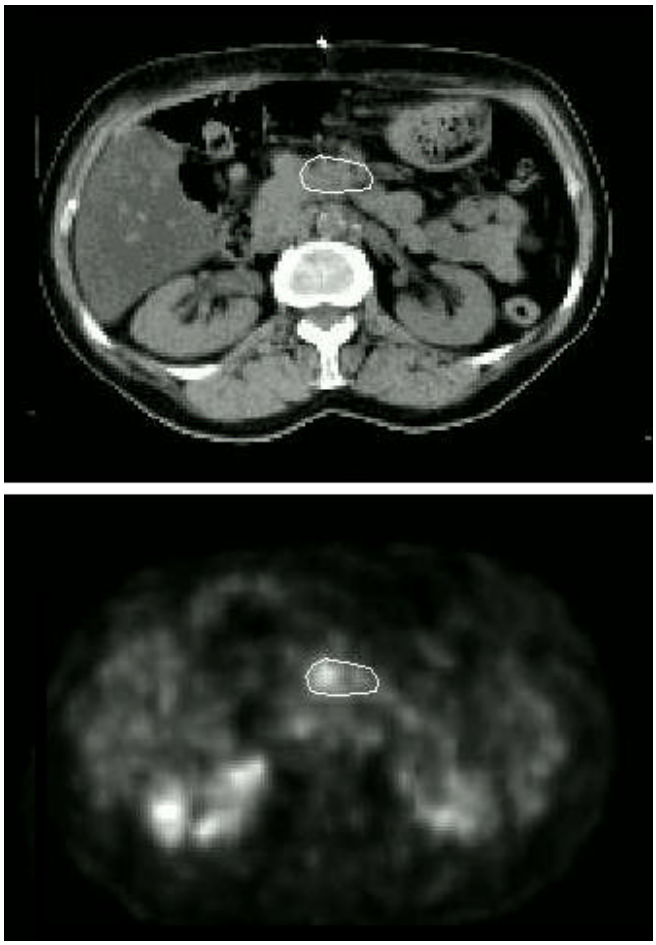

Fig. 1. The contour of the pancreatic tumour drawn on two registered CT(up) and PET(down) slices. The hypermetabolic area, evidenced in PET image, guides the definition of the anatomical zone involved in the neoplastic process.

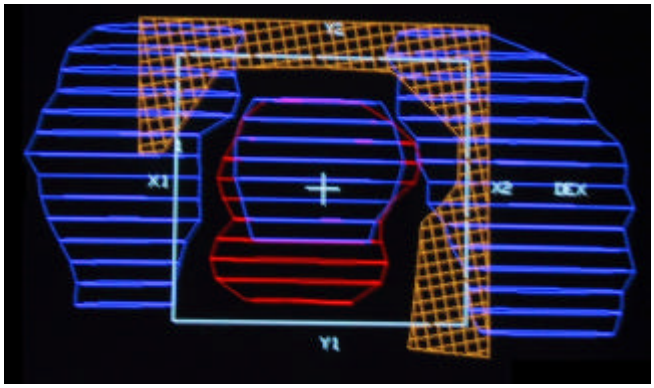

Fig. 2. A representative coronal projection view used on the treatment planning system, showing the contours of target volumes and dose limiting organs. Laterally: critical organs (kidneys, blue color). In the middle: target volume (part of pancreas) as identified by CT alone (blue) and as identified by combined CT/PET (red); irradiation field (white box); wedges used to limit dose to critical organs (orange grid).

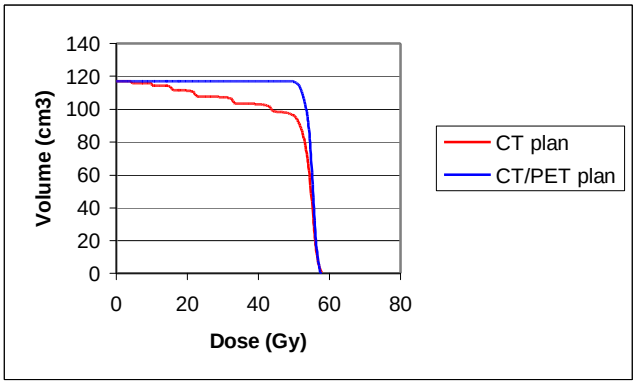

Fig. 3. Cumulative dose-volume histogram relative to the target volume as defined by CT/PET integrated studies. In red, the curve relative to the irradiation plan based on CT data, in blue the curve relative to the irradiation plan based on combined CT/PET data.

IV. Conclusion

In this work a procedure based on multimodal CT/PET integration is proposed to optimize radiotherapy planning. The registration accuracy (less than 2 pixels in plane and less than slice thickness axially, with respect to CT) was found to be dependent on patient repositioning and axial sampling. The procedure applied to the case of a patient affected by pancreatic tumour showed an improved definition of the tumour mass by the synergistic use of functional PET and anatomical CT information. The more accurate definition of the target volume could improve radiotherapy treatment by a better planning of the irradiation beams.

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